ANALYSIS AND PREDICTION OF VISIBILITY AT SEA

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OF VISIBILITY AT SEA

by

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ABSTRACT

Visibility over the sea is one of the prime environmental parameters affecting naval operations and current forecasting methods for visibility are inadequate. Low visibilities at sea are related to moisture in the air and saturation of the air. The Fleet Numerical Weather Facility at Monterey produces a field of the difference in vapor pressures of the sea and the air and this field may be used as a humidity index. An attempt is made to use this field plus other environmental parameters, such as air temperature, to produce a regression equation for visibility. Humidity, air temperature and wind speed are determined to be the most important variables, however, the equation is inaccurate when the visibility is low.

Graphical techniques were applied to these variables and a scattergram of visibility as a function of air temperature and vapor pressure difference revealed a significant relationship that was used to forecast fog probability and visibility.

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TABLE OF SYMBOLS AND ABBREVIATIONS

c	constant (.18)
e_a	vapor pressure of the air
e_w	vapor pressure of the sea
k	constant (.15)
r	distance
t	time
T_a	dry bulb temperature of the air
T_{dp}	dew point temperature of the air
T_w	temperature of the sea
V	surface wind speed

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1. Introduction

Modern technology has provided recent and rapid advances in the fields of meteorology and oceanography including numerical computer techniques, however, the ultimate value of any new technology lies in its application to consumer products. If the U. S. Naval Weather Service is considered as a producer of services and the Naval Commander is the consumer then the product involved is that information concerning the environment that the Commander needs to make rapid and accurate decisions. This information includes, but is not limited to, such parameters as precipitation, cloud distribution, sea state, wind and visibility. The analysis and forecasting of some of these parameters has been improved by the application of the digital computer, however, this technique has not been applied to the prediction and analysis of visibility.

Visibility at sea has always been a problem to the Naval Meteorologist, as well as others concerned with transport over the sea. Commercial shipping interests are faced with the danger of collision at sea in areas of low visibility. Naval Commanders have additional factors to consider besides collision. Low visibility may restrict air operation and training exercises. It also may increase transit times if speeds must be reduced. In many naval operations the effective threat of electronic countermeasures has precluded the use of radar and resulted in visual search becoming

all important. Therefore, while the Commander may want to avoid areas of low visibility or hide in them, it is important that the U. S. Naval Weather Service have an accurate and prompt technique for the prediction of visibility at sea.

At the present time, forecast visibilities are based on reports from ships in the general area, knowledge of air mass and frontal movements and climatology. This method may suffer from the lack of reported data and during war the number of reports would be even smaller.

This lack of reported data also prevents direct analysis by the computer and the fact that low visibility areas are not generally advected complicates the problem of forecasting. However, visibility is dependent on the interaction of other parameters that lend themselves to analysis and prediction by objective methods.

One of the most important of these parameters is the humidity of the air. The U. S. Naval Fleet Numerical Weather Facility, located at the Naval Postgraduate School, Monterey, California, produces a humidity field for the Northern Hemisphere. It was at the request of the Fleet Numerical Weather Facility that the research connected with this paper was conducted.

The author wishes to express his appreciation for the assistance and encouragement given by Doctor T. Laevastu of the Fleet Numerical Weather Facility and Professor G. Haltiner of the U. S. Naval Postgraduate School. Thanks are also given

to the Fleet Numerical Weather Facility for providing the necessary data.

2. Background

Atmospheric obscurations or restrictions to visibility are caused by the presence of a large number of minute particles held in suspension in the air. [1]

These may be solid particles of smoke, sand or dust or hydrometeors such as water droplets and ice particles.

The solid particles in the air are usually a problem only over land or in ocean areas adjacent to large cities or deserts. Occasional dust storms will blow far out to sea, however, these phenomena will not be considered in this paper.

The hydrometeors or moisture particles may be further divided into precipitation and suspended moisture. Precipitation is primarily a restriction to visibility in storms and fronts and these areas may be forecast by standard techniques for analysis and forecasting of fronts and pressure systems.

The suspended moisture in the air becomes more and more of a restriction to visibility as the particles grow in size. There is always water vapor in the air but this only becomes visible when it condenses on hydroscopic condensation nuclei. If these suspended moisture particles become a definite restriction, they are referred to as fog or haze.

Fog is defined by the Admiralty Weather Manual [1] as a condition producing a horizontal visibility of less than 1/2 mile, while haze results in visibility between 1/2 mile and one mile.

For the purposes of this paper the definition suggested by Byers will be used. [4] He states that fog is a stratus cloud cover that forms at the ground or close to it as to affect the surface visibility.

Condensation on the nuclei only takes place after the air has become saturated. [5] This saturation of the air is caused by either cooling of the air to saturation temperature or evaporation of moisture into the air. Fog is classified by type according to the processes causing either the evaporation or the cooling. [12] Frontal fog is associated with the passage of frontal weather bands and the forecasting of this type of fog is related to frontal forecasting. Radiation fog takes place over land during the night. The ground radiates and cools and in turn cools the air to saturation temperature. The ocean also radiates during the night and cools but convection in the water replaces the surface heat and keeps the cooling to a minimum and thus prevents the formation of radiation fog. Sometimes radiation fog will drift from land over the water, but this only takes place near the shore. Advection fog or sea fog as it is called is the type that appears over the open ocean. [4]

Moist air is advected over colder water and is cooled to the saturation point by latent and sensible heat exchange between the air and water.

There has been very little study on the subject of sea fog and its prediction or the conditions that form it. G. I. Taylor studied fog in the vicinity of the Grand Banks prior to 1917 and decided that wind speed and the difference between air and sea temperatures were the dominant factors. [11]

Laevastu has postulated that sea temperature is the primary factor because of the rapid rate with which the air assumes the characteristics of the sea it passes over.

Because fog formation and low visibility are dependent on saturation it is apparent that humidity of the air is an important variable to be considered.

The Fleet Numerical Weather Facility produces a hemispheric chart of vapor pressure difference between the air and the sea and data on other important parameters such as air temperature are available from ship weather reports.

3. FNWF Vapor Pressure Program

The Fleet Numerical Weather Facility at Monterey produces a comprehensive program of oceanographic charts by numerical methods using the CDC 1604 digital computer. Part of this oceanographic program consists of the forecasting and analysis of sea surface temperatures and mixed layer depths. [7, 10] These products depend, in great part, on a detailed knowledge of heat exchange between the air and the atmosphere. This heat exchange includes both sensible (Q_h) and latent (Q_e) heat exchanges. Sensible heat depends on the difference between the air and sea temperatures, while latent heat depends on the difference between the vapor pressures of the air and the sea. Laevastu has developed the following equations for the Q_e term.

If $(e_w - e_a)$ is positive;

$$Q_e = (0.26+0.077V)\ (e_w-e_a)L_h$$

If (e_w-e_a) is negative;

$$Q_e = 0.077V(e_w-e_a)L_h$$

The vapor pressure of the air is computed from reported values of dew point temperature from ship reports and the following relationship:

$$\log_{10}e_a = 9.405-2353/T_{dp}$$

The vapor pressure of the sea water is computed using the water temperature in place of the dew point temperature, but including a factor of .98.

$$\log_{10} e_w = .98(9.405 - 2353/T_w)$$

Because of the lack of data at sea, any analysis of the vapor pressure difference field over the sea should be based both on initial values from reports and on computation of the responses of the air properties to the sea as the air is advected over the water. FNWF has solved this problem by using the following equation by Amot for the computation;

$$e_w - e_a = (e_{w_0} - e_{a_0}) e^{-kt} \left(\frac{c}{k} + \frac{1}{k} V_r \frac{\partial e_w}{\partial r} \right) \left(1 - e^{-kt} \right)$$

An equivalent equation, that is more suitable for numerical computations, has recently been introduced at FNWF; [7, 10]

$$\frac{\partial e_a}{\partial t} + \vec{V}_g \cdot \nabla e_a = k(e_w - e_a) - c$$

The $(e_w - e_a)$ field has been verified by FNWF and a sample of this verification is listed in Table I.

4. Objectives

a. Investigate the effects of available meteorological and oceanographic parameters on visibility at sea and fog formation. This includes not only humidity but the other parameters included in ship weather reports.

b. Relate the Fleet Numerical Weather Facility chart of vapor pressure difference, as an index of humidity, to visibility.

c. Determine which of the investigated parameters have the most effect on visibility by both numerical and graphical techniques.

d. Attempt to obtain a linear regression equation for visibility as a function of the most important parameters.

e. Determine if it is feasible to use Fleet Numerical Weather Facility vapor pressure charts plus other parameters available to FNWF along with numerical computer techniques to produce large scale analysis and forecast charts of visibility at sea.

5. Data Compilation

Raw data was provided by the Fleet Numerical Weather Facility and consisted of hemispheric charts of vapor pressure difference $(e_w - e_a)$ and world-wide ship weather reports for the same times. The data was from selected days in the months of April and May, during both 1965 and 1966. This time of year is a period of high fog incidence over the northern oceans. The particular dates and times of the charts used are listed in Table II.

Selection of data points was restricted to the North Atlantic ocean because of the density of the reports in this area and the importance of the area to commercial shipping and naval operations. Only points north of 20 degrees north latitude and south of 70 degrees north were used due to the boundary limitations of the computer. The area was further restricted to points at least one grid width from land to eliminate land effects such as radiation fog and also because the vapor pressure program produces the best results away from land. One grid width is about 150 NM.

The ship reports to be used were selected from the area described above. Only complete reports with the same date time group as the chart of $(e_w - e_a)$ with which they were to be compared were used. All reports with precipitation indicated in the present weather column were not used because the visibility reported in such cases would be related more to the precipitation than to any moisture particles suspended in the air.

The actual extraction of the data began with the analysis of the FNWF vapor pressure charts.

Figure 1 is an example of such an analysis which is printed on a 1:30,000,000 polar stereographic projection and analyzed at one millibar intervals.

To relate particular ship reports to the $(e_w - e_a)$ charts it was necessary to use a plastic grid overlay over the chart. Figure 2 shows the grid overlay in position over the analyzed chart. The I and J coordinates of the grid are printed on the overlay and are visible in the Figure. The ships' positions, as reported on the ship weather report, are changed by FNWF to I and J grid coordinates and thus it was possible to find the position of the ship on the chart and extract the value of $(e_w - e_a)$. This was done for each of the data points and the values recorded with the appropriate ship weather report.

Figure 3 is a sample of a ship weather report as it is recorded by FNWF. From each selected report the following variables were extracted:

1. Air temperature (T_a)
2. Dew point temperature (T_{dp})
3. Dew point spread $(T_a - T_{dp})$
4. Air-sea temperature difference $(T_a - T_w)$
5. Wind speed (V)
6. Three hour pressure change

7. Time of report

8. Visibility

9. Vapor pressure difference (e_w-e_a) which had come from the FNWF charts.

Because visibility was to be the dependent variable it was recorded in three forms to allow different possibilities of correlation.

These forms were: 1) visibility code as it is recorded on the ship weather report and which is non-linear with respect to actual distance, 2) visibility in nautical miles (NM) and 3) fog or no fog. All these forms of the visibility parameter were recorded along with the other parameters. Eleven hundred data points were thus treated and used for the analysis.

6. Data Analysis

After selection of the parameters to be analyzed and extraction of the data from the charts and ship reports the next step was analysis. The purpose of the analysis was to check each of the independent variables for correlation with visibility and the effect each had on visibility.

Two techniques were used: 1) numerical analysis of the variables using the CDC 1604 digital computer and regression techniques and 2) graphical analysis using scattergram techniques. These two methods will be discussed separately.

Numerical Analysis

The computer center at the U. S. Naval Postgraduate School maintains a library of subroutines for use with the CDC 1604 computer. This library includes several numerical correlation programs, but on the basis of their limitations and restrictions the list was narrowed down to three. All three of these programs were tried at least once with the same sample of data to observe which would best suit the objectives of the paper. These three programs are: 1) BIMED 09, 2) BMD 03R, and 3) BMDX 13. After comparing the respective results it was decided that BIMED 09 would be used for the numerical analysis.

BIMED 09 is a linear regression program for use with one dependent variable and n independent variables. It performs a

multiple stepwise regression that adds independent variables one at a time and prints the results for each step. At each step the variable added is the one that gives the best goodness of fit. Transformations of variables and transgeneration of new variables are both possible and weighting factors may be applied to the data.

All these features were used with the exception of the weighting factors. Results programmed for printing include sums of variables, raw sums of squares, average values of variables, residual sums of squares, and simple correlation coefficients.

For each step in the regression, the variable used, F level, standard error, regression constant, and regression coefficient are also printed. A comparison of actual and predicted values of the dependent variable and the deviation may also be printed.

The variables were tried in different combinations and each one of these combinations was referred to as a problem. Twenty eight "problems" were analyzed with the computer. Half of these problems used (e_w-e_a) as the humidity parameter and half used the dew point spread, this being the only difference between the two groups. This was done to insure that the vapor pressure difference would indeed act as a valid humidity index. In each of the problems (e_w-e_a) produced the same general results as dew point spread.

The fourteen problems where the vapor pressure difference was used were further divided into two groups of seven based on values for the constant term in the regression equation. At first the data was processed and the constant term was restricted to zero. The dependent variable was then tried in seven different forms:

(1) visibility code from ship reports

(2) square root of visibility code

(3) $\log_{10}$ of the visibility code

(4) fog or no fog

(5) visibility in nautical miles

(6) square root of visibility in NM

(7) $\log_{10}$ of the visibility in NM

The square root and $\log_{10}$ values were computed using the transformation feature of the BIMED 09 program and the fog - no fog values were a result of transgeneration by directing that all visibilities less than one mile be considered fog and all greater than one mile be no fog. The values of visibility code were changed to visibility in nautical miles by use of Table III.

The same seven variations of the dependent variables were then used allowing the computer to produce a value for the constant term in the regression equation.

The statistical results of each problem were compared to results of the other problems.

The relative success of each problem was based on the prediction of the fog cases by use of the related regression equation. Print-outs of actual vs predicted visibilities were obtained and evaluated. Two percentages were computed: 1) the percent of actual fog cases that were predicted, and 2) the percent of predicted fog cases that verified. Standard error of estimates were also compared.

Those problems in which the constant term was not restricted to zero produced the smallest standard errors, however, they did a poor job of fog prediction. In each of the problems in this group the independent variables were selected by the computer in the following order:

1) Humidity (e_w-e_a)

2) Air temperature T_a

3) Wind speed

Problem number eight is an example of a problem in this group. Vapor pressure difference was used for the humidity parameter and the visibility code was used for the dependent variable. The constant term in the regression equation had a value of 6.34656 and the standard error of estimate was 1.02, which was one of the lowest obtained. The percentage of actual fog cases predicted by this equation was 25%, while the percent of predicted cases that were really fog was 100%. The regression equation is a linear function and the large constant

term, while improving the standard error for the curve as a whole, caused larger errors at the end of the curve where low visibilities occur. (See Table IV)

In each problem where the constant term was restricted to zero the standard error was larger, but the fog prediction was better. In these cases the line of the regression equation was being forced through the origin bringing it closer to the low values of visibility. Problem number five fell in this category and produced the best results for fog prediction of all the numerical problems. The percent of actual fog cases predicted was 75%, and 19% of the predicted cases were fog. The standard error was 2.14. This problem also used the vapor pressure difference as the humidity parameter and visibility code for the dependent variable. (See Table V) In all the problems where the constant term was zero, the computer selected the significant variables in a different order:

1) Air temperature

2) Wind speed

3) Humidity

When the constant term was used, all the deviations between actual and predicted values for fog cases were large negative values caused by the large constant term. Because of this a value of 3.17 was used for the constant while retaining the regression coefficients from problem number eight. This improved

the results to 75% of the fog cases being predicted and 40% of the predicted cases being fog.

The difference between sea and air temperatures and the time of report were significant variables in only three problems and then were only considered after air temperature, wind speed, and humidity.

In problem number five they decreased the standard error from the 2.21 with the first three variables to 2.14 with all five. The other independent variables, dew point temperature and three hour pressure change, were insignificant in all the problems.

Graphical Analysis

Based on the results of the numerical analysis air temperature, wind speed, and vapor pressure difference for independent variables, and the visibility code figures for the dependent variable were considered for the graphical analysis. These variables were plotted in different combinations on scattergrams. Sea temperature and the difference between sea temperature and air temperature were also tried as variables because of the importance placed on them by Laevastu (8) and Taylor (11).

In addition, graphs were plotted of vapor pressure difference vs dew point spread and wind speed vs visibility.

The plot of vapor pressure difference vs dew point spread was quite scattered, however, when values of plus or minus one degree are considered for the dew point spread the plotted points fit a linear function. (See Figure 4)

Wind speed vs visibility showed no meaningful relationship. All visibilities were present at all wind speeds up to 48 knots.

Of all the combinations of the variables suggested by the numerical analysis the one that gave the most meaningful results was that of visibility code as a function of air temperature and vapor pressure difference. Air temperatures were plotted on the vertical axis and $(e_w - e_a)$ on the horizontal axis and the points were plotted with the values of visibility code. (See Figure 5) If the zero value for $(e_w - e_a)$ is considered as saturation, then 76% of the fog cases are in the saturation area left of the zero point; in other words, where the vapor pressure of the air would be higher than that of the water. Only 39% of all the points left of the zero point were fog cases and this is nearly the same results as obtained from the best numerical problem. Further analysis of the data points in the saturated zone showed a direct relationship between fog cases and air temperature. Data points that were in the saturated zone with respect to vapor pressure difference, but had high air temperature, were not likely to have low visibilities. A best fit curve, which is depicted on Figure 5, was then smoothed on the graph in an attempt to divide the areas of fog and no fog. The resulting curve had the equation:

$$X=A+BY^3$$

The area to the left of this curve was then considered as the modified saturation zone, and in this area 72% of the actual

fog cases were present while the percentage of predicted cases that were fog rose sharply to 60%. Half of the remaining 40% were cases with visibilities less than two miles.

While the majority of the fog cases had wind speeds of less than 20 kts, any attempt to restrict fog prediction to that range resulted in the exclusion of a significant number of actual fog reports.

Visibility as a function of the difference in air and sea temperatures and the difference in vapor pressures was plotted, but the fog cases were scattered across the graph and no conclusions could be made. The majority of the values for the difference in temperatures for the 1100 data points were less than two degrees.

The temperature of the water was computed for each point and visibility was plotted as a function of this and vapor pressure difference.

The resulting scattergram showed a strong resemblence to Figure 5, because of the interaction between the sea and air that results in the small differences in sea-air temperatures. There was more scattering of low visibility cases, however, and the fog prediction percentages were not as high.

Applications

The scattergram of visibility as a function of air temperature and vapor pressure difference gave the best results in fog

prediction, and applications for a forecasting method were based on this graph. Two forecasting methods were sought. The first was a method to forecast fog probability in terms of percentages from zero to one hundred. The other was a method to forecast visibility in miles or in terms of the visibility code.

Fog probability lines were constructed directly on the scattergram. (See Figure 6) The percentages were based on the fog cases in the 1100 data points.

Visibility prediction directly from the scattergram was attempted but it was difficult to fit curves in the area where the visibility was greater than one mile. Smoothing of the data was then undertaken by use of a Laplacian technique. Average values of visibility were computed at each intersection on the graph by averaging all the values in an area 10 mb by 4 degrees. The intersections on the graph were 5 mb and 2 degrees apart so each data point was thus considered in the average value for each of the four intersections around it. This provided the necessary smoothing and it was then possible to construct isolines of visibility. The values of these lines were in terms of the ships visibility code and it would be a simple matter to convert them to miles. Figure 7 shows the smoothed values and the visibility lines.

7. Conclusions

1) The vapor pressure difference field that is computed by the Fleet Numerical Weather Facility is a valid humidity index.

2) Air temperature, wind speed and humidity are the primary parameters effecting visibility over the sea. When the humidity reaches 100% and the air is saturated fog forms and visibility becomes quite low. When the vapor pressure difference is used as the humidity parameter air temperature must be considered before predicting fog. Air temperature and sea temperature are closely related and the difference between them becomes smaller as time passes.

3) Ordinary regression equations are not applicable to fog prediction because the relationships between visibility and the other parameters are apparently non-linear.

4) Fog is caused when saturation of the air occurs and a completely accurate field of relative humidity could be transposed into a visibility field where saturation would correspond to fog formation. This is not true for the vapor pressure difference field, because there is a difference in the temperatures of the sea and air. If the air is warmer than the sea, then the air itself is not truly saturated when the vapor pressure of the air is equal to that of the water. If the temperatures were equal and the vapor pressures equal then saturation would be present. By the same reasoning, if the air is colder than the water, the air will

be saturated when e_a is still less than e_w. These anomalies occur because the saturation vapor pressure of the air is a function of the temperature of the air and not of sea temperature.

5) There is greater probability of the air temperature being warmer than the sea temperature for high values of air temperature, and cooler than the sea for low air temperatures. The modified saturation curve in Figure 5 follows this concept.

6) For fog prediction the best results are obtained by plotting visibility as a function of air temperature and vapor pressure difference. 72% of the fog cases were predicted and 60% of the predicted cases were fog.

7) A smoothed version of the above graph is adaptable to the prediction of visibility in miles.

8) Using the above described methods, wind spread cannot be considered because wind mixing depends on the thickness of the inversion layer. However, wind speed is a term in the equation for the difference in vapor pressures and a large wind speed will result in a large difference and decrease the chance of low visibilities being forecast.

9) The primary limitation in this investigation was in the use of reported ship visibilities as the dependent variable. Observations of visibility at sea are not accurate.

10) It is feasible to program fog probability and visibility charts for the open ocean areas using the vapor pressure difference field and air temperature field.

Table I

Interval in mbs	Ship reports	Land reports
7 or more	12	139
5 to 6.99	3	43
3 to 4.99	26	127
1 to 2.99	60	295
-1 to .99	241	867
-3 to -1.01	41	235
-5 to -3.01	10	68
-7 to -5.01	2	34
under -7	2	18

FNWF verification of one chart of $(e_w - e_a)$ based on comparisons of actual and prediction values.

Table II

1965	1966
00Z 2 May	00Z 1 April
12Z 2 May	12Z 1 April
12Z 4 May	00Z 2 April
12Z 5 May	12Z 2 April
00Z 6 May	00Z 3 April
12Z 6 May	12Z 3 April
00Z 7 May	00Z 4 April
00Z 8 May	12Z 4 April
12Z 8 May	00Z 5 April
00Z 9 May	12Z 5 April
00Z 10 May	
12Z 10 May	
00Z 11 May	
12Z 11 May	
00Z 12 May	
12Z 12 May	
00Z 13 May	
00Z 14 May	
12Z 14 May	
00Z 15 May	
12Z 15 May	
00Z 16 May	

Dates and times of charts and reports used in study

Table III

Second digit of code figure	Visibility
0	less than 50 yd
1	50 yd
2	200 yd
3	1/4 NM
4	1/2 NM
5	1 NM
6	2 NM
7	5 NM
8	10 NM
9	25 NM

Visibility code for ship weather reports

Tabe IV

Stepwise Regression

Problem No. 8

Variable	1 - T_a	2 - T_{dp}
	3 - T_a-T_w	4 - wind speed
	5 - time	6 - e_w-e_a

Simple Correlation Coefficients

X(1) vs Y = .398	X(2) vs Y = .276
X(3) vs Y = -.176	X(4) vs Y = -.202
X(5) vs Y = .009	X(6) vs Y =.519

Standard error of Y = 1.305

Regression steps

Step no. 1 Variable entering - 6
F level - 183.86
Standard error of estimate - 1.1169
Constant - 6.59765

Step no. 2 Variable entering - 1
F level - 46.52
Standard error of estimate - 1.0691
Constant - 5.95737

Step no. 3 Variable entering - 4
F level - 16.55
Standard error of estimate - 1.0528
Constant - 6.34652

Regression coefficients

Variable	Coefficient
1	.00494
4	-.01976
6	.02978

Statistical Results of Numerical Problem Eight

Table V

Stepwise Regression

Problem No. 5

Variables	1 - T_a	2 - T_{dp}
	3 - T_a-T_w	4 - Wind speed
	5 - time	6 - e_w-e_a

Simple Correlation Coefficients

X(1) vs Y = .928	X(2) vs Y = .882
X(3) vs Y = -.155	X(4) vs Y = .826
X(5) vs Y = .680	X(6) vs Y = .834

Regression steps

Step No. 1 Variable entering - 1
F level - 3135.69
Standard error of estimate - 2.8144
Constant - 0

Step no. 2 Variable entering - 4
F level - 187.75
Standard error of estimate - 2.4001
Constant - 0

Step no. 3 Variable entering - 6
F level - 85.78
Standard error of estimate - 2.2183
Constant - 0

Step no. 4 Variable entering - 5
F level - 31.65
Standard error of estimate - 2.1528
Constant - 0

Step no. 5 Variable entering - 3
F level - 6.54
Standard error of estimate - 2.1408
Constant - 0

Regression coefficients	Variable	Coefficient
	1	.03631
	3	-.01136
	4	.09250
	5	1.05074
	6	.04901

Statistical Results of Numerical Problem Five

Figure 1 - Chart of Air-Sea Vapor Pressure Difference Field ($e_w - e_a$)

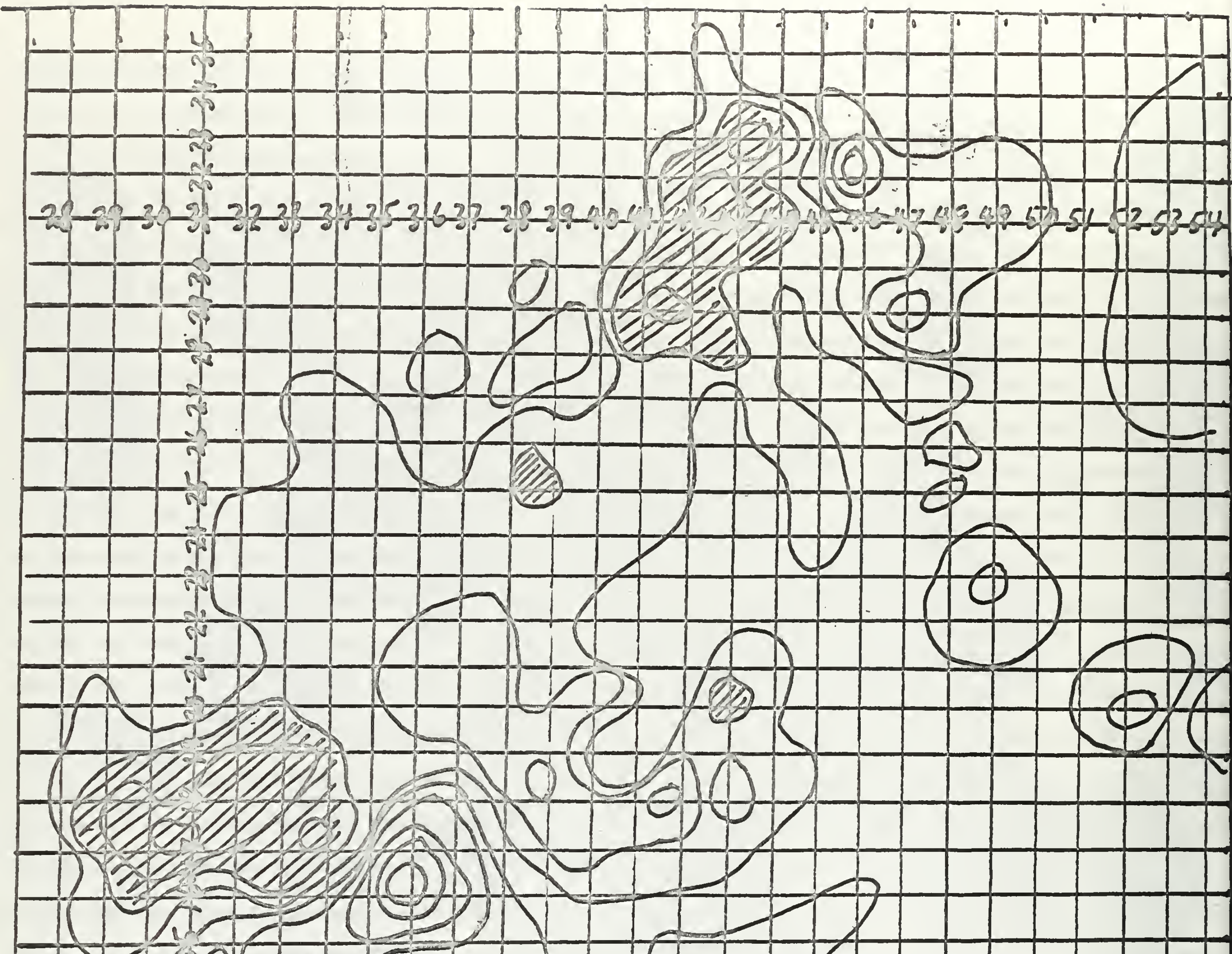
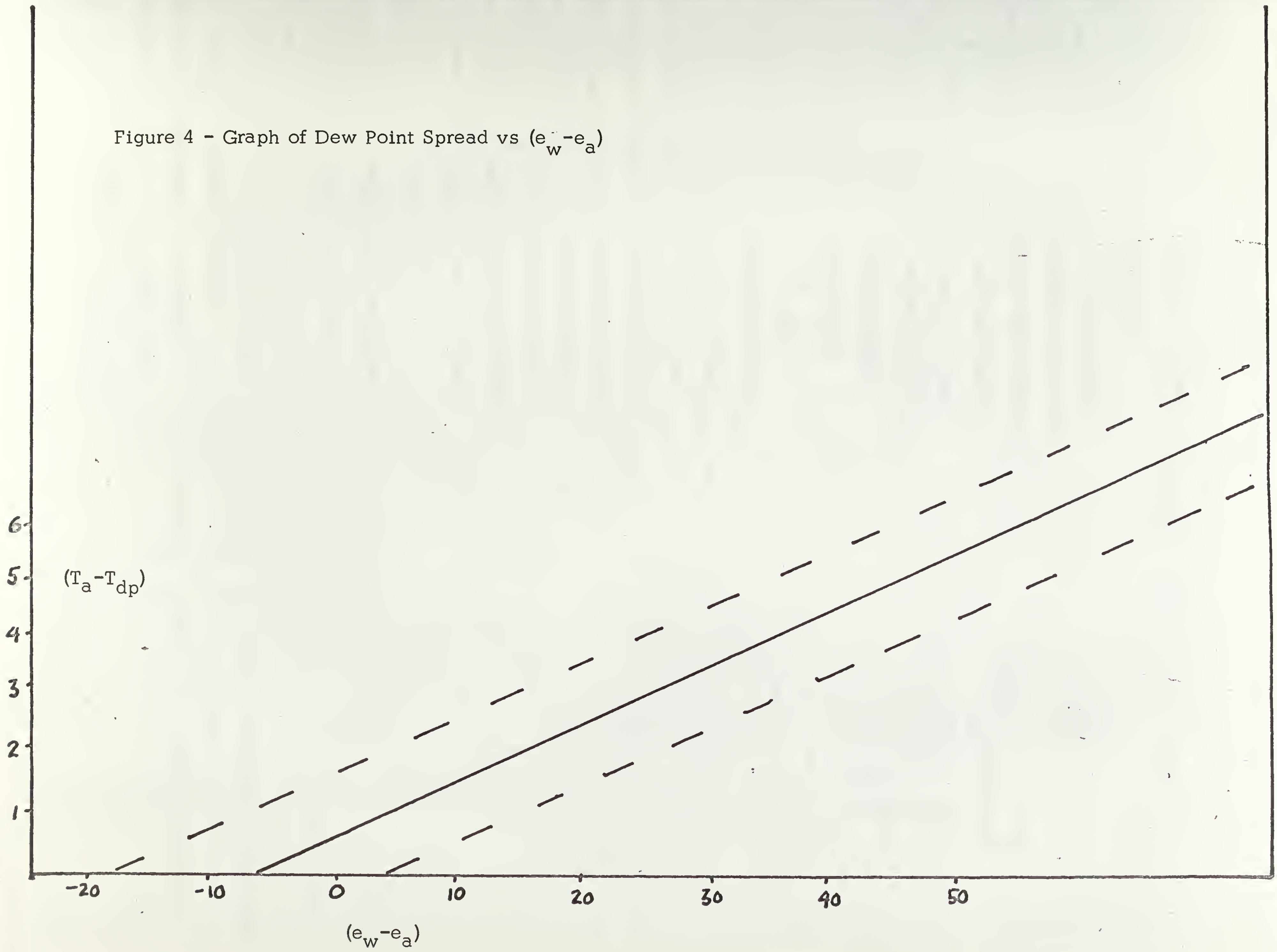


Figure 2 - Grid Overlay Over Analyzed Field of $(e_w - e_a)$

GVCT	- ship call sign
0	- time of report
550	- I column
2623	- J row
6	- ship course
6	- ship speed
+137	- pressure diff.
+220	- dry bulb temp.
-15	- T_a-T_w
+165	- dew pt. temp.
-20	- pressure change
2	- wave period
2	- wave height
2	- wave direction
4	- swell period
4	- swell height
33	- swell direction
2	- wind direction
8	- wind force
6	- sky cover
1	- past weather
6	- amount low cloud
3	- type low cloud
0	- type mid cloud
0	- type high cloud
5	- height cloud base
3	- present weather
98	- visibility

Figure 3 - Sample ship weather report as used by FNWF

Figure 4 - Graph of Dew Point Spread vs $(e_w - e_a)$



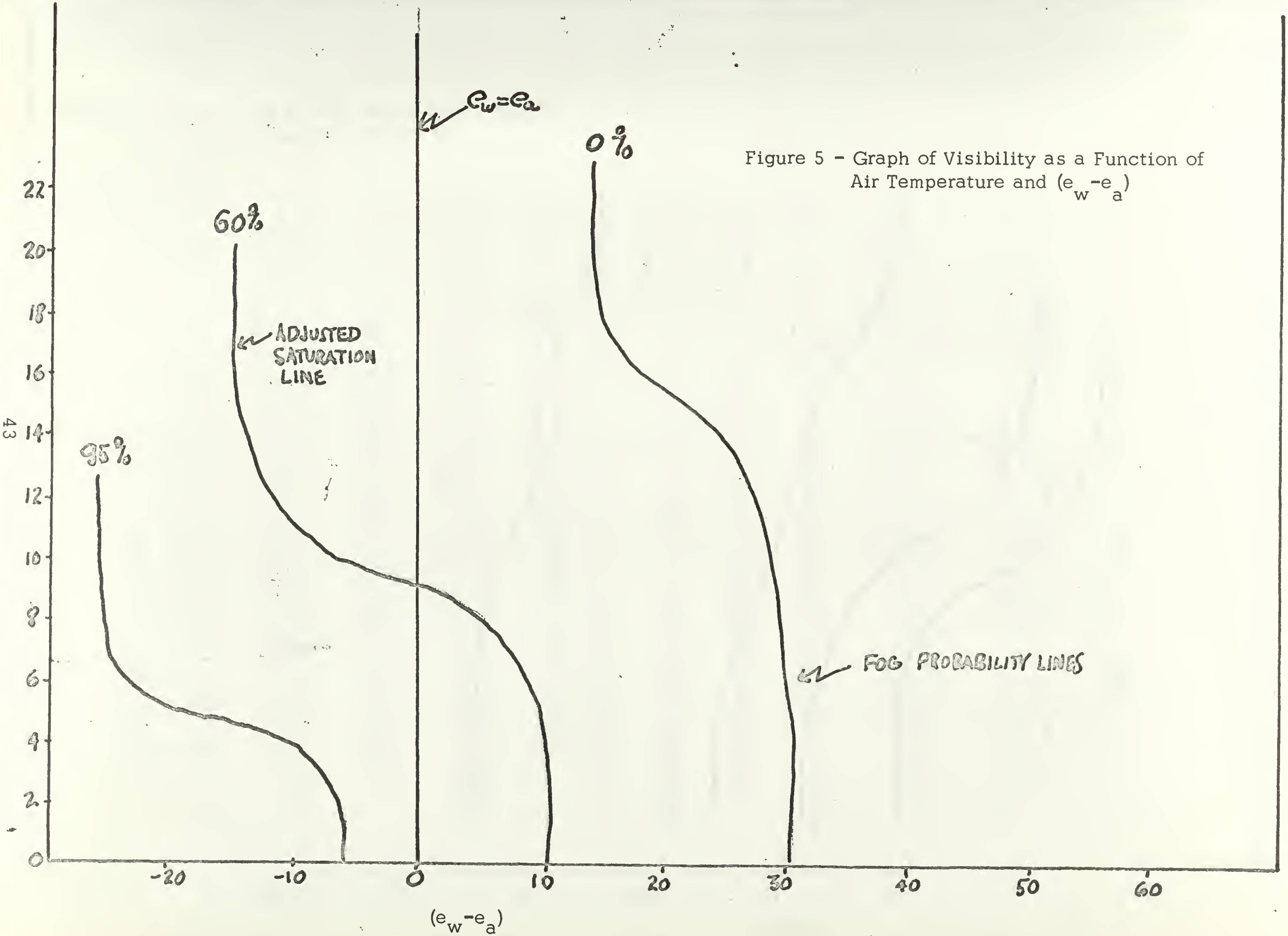
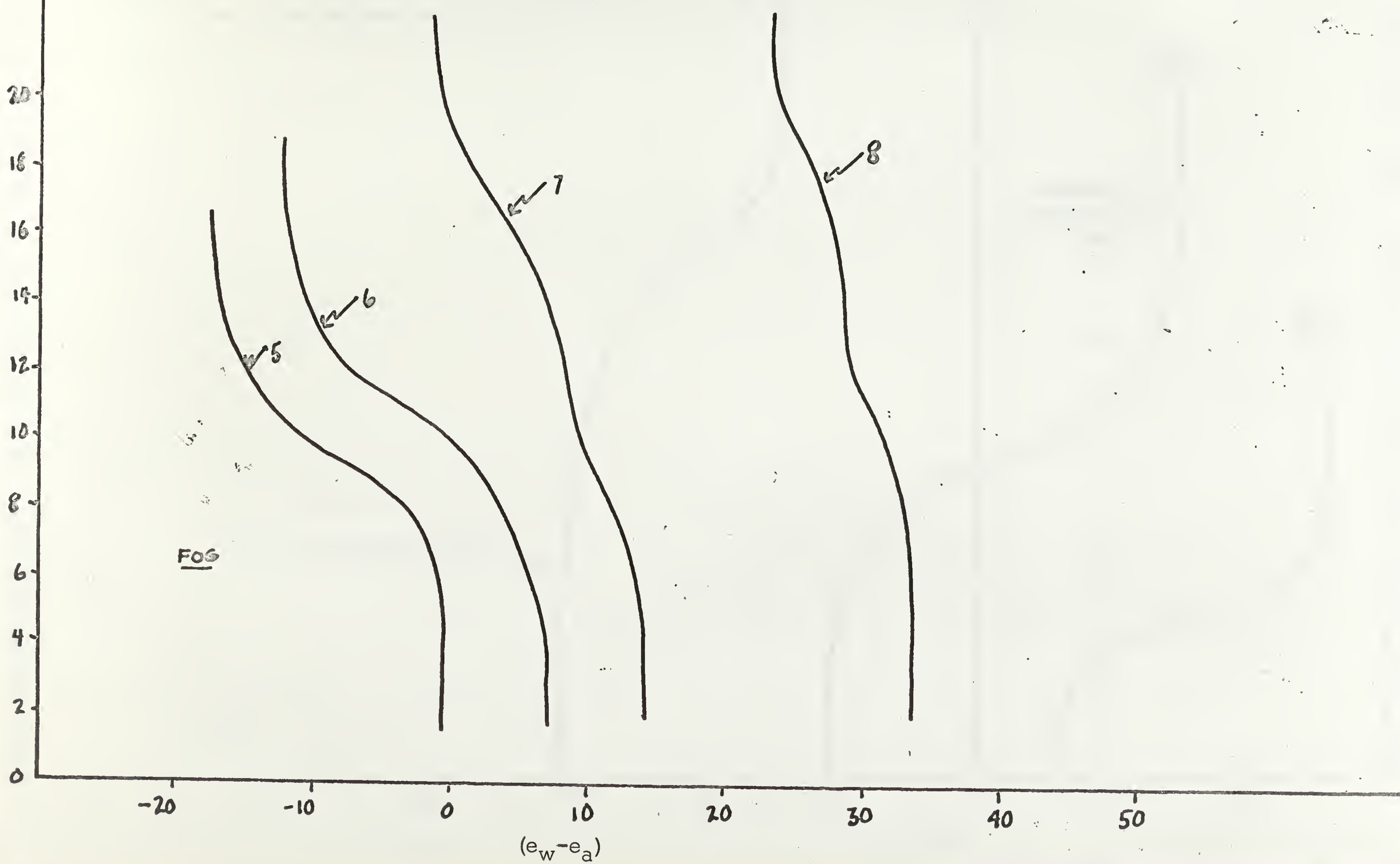


Figure 5 - Graph of Visibility as a Function of Air Temperature and $(e_w - e_a)$

Figure 6 - Smoothed Plot of Visibility as a Function of Air Temperature and $(e_w - e_a)$



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13. ABSTRACT

This paper is concerned with the problem of visibility at sea and fog over the sea. Restrictions to visibility in general are discussed and suspended moisture is related to low visibilities at sea. Fleet Numerical Weather Facility at Monterey produces a field of the difference between the vapor pressures of the sea and air. This field is used as a humidity index to determine the moisture in the air and is related to visibility. 1100 data points from the North Atlantic were analyzed and an attempt made to produce a linear regression equation. The regression equation proved to be most inaccurate in the area of low visibilities. A scattergram of visibility as a function of air temperature and the vapor pressure difference revealed a significant relationship. Using this relationship it is possible to forecast visibility and fog probability. (U)

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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